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PROPERTIES AND PERFORMANCE OF A SIMPLE ELECTRON-HADRON CALIBRATION BEAM IN PROTON WEST

B. Cox, M. Binkley, T. Kondo, and C. T. Murphy

Fermilab,

M. Goodman† and J. Nagy‡

The Johns Hopkins University

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ABSTRACT

A simple, low-flux electron-hadron beam has been created in the Proton West Area of Fermilab by inserting a beryllium target, followed by a lead converter, into the primary proton beam. The beam produces a few thousand electrons with 10^{10} protons incident on the target with a momentum bite of $\geq$ 4% and a purity of about 60% in the 10-30 GeV energy range. The beam has been used to calibrate electromagnetic detectors used in proton experiments in the same area.

† Present address: Harvard University

‡ Present address: Brookhaven National Laboratory

The extracted proton beam in the Proton West area of Fermilab was constructed with refocussing and collimation sections, as described earlier[1], in order to create a "halo-free" beam for experiments in the Proton West experimental area. Using the existing collimators, bending magnets, and quadrupole magnets of this section of the beam, we have produced a momentum-analyzed electron beam of sufficient quality and intensity to calibrate the lead glass arrays used in one of the experiments in the Proton West experimental areas. The only addition to the beam is a remotely-removable beryllium target at the upstream end of the refocussing section. This feature of the Proton West area allows for the calibration of electromagnetic shower detectors in the same place as they are used in the study of proton-nucleon interactions.

The optics of the beam are shown in Fig. 1. The primary proton beam interacts with 5" of beryllium at the end of enclosure PW-A, producing charged and neutral mesons. The photons from the π^o decay are converted into electron-positron pairs in 3/8" of lead (two radiation lengths) 2" downstream from the end of the beryllium. The lead thickness was selected to maximize the flux of 16 GeV electrons with a 400 GeV incident proton beam. The Monte Carlo program which found the optimum length used a radial scaling distribution for the generation of π^o mesons and a simple shower routine for the conversion process. The secondary beam following the lead converter is a mixture of charged hadrons, electrons, and muons.

The vertical bending magnet just before the target steers the remnant unscattered protons to a point 4 cm from the edge of the vertical collimator in the next enclosure, as shown in Fig. 1, where the protons are dumped in a 2.5 meter length of steel. Thus the production angle of the neutral beam which is directed towards the center of the beam apertures is 0.6 mrad. This selection of production angle was based on an empirical study of backgrounds produced by the dumped proton beam as a function of production angle. At this angle, the ratio of transmitted electrons to background particles is approximately maximized. At greater angles, electron flux is lost with no gain in purity; at smaller angles, backgrounds from interactions of the remnant protons with the surfaces of the angle-defining collimators in PW-B become noticeable.

The acceptance in the horizontal plane is 0.152 mr as determined by the 1.5" bending magnet aperture in PW-C. In the vertical plane, a 4 mrad bend in PW-B disperses the beam and the momentum bite is defined by the collimator in PW-C. Fig. 2 shows the cuts made in the ΔP-θ_y plane by these two collimators, where θ_y is the particle angle in the vertical plane at the target. The acceptance of the beam is defined as the area of the central trapezoid of Fig. 2 times the horizontal acceptance angle and is 0.106 μster-% for the conditions of Fig. 2.

The actual width of the momentum distribution transmitted by the beam is a function of three variables, as can be seen from Fig. 2: the two collimator apertures and the position of the particle at the target. The contribution of the proton beam width in the vertical plane at the target to the momentum width is minimized by operating the pretarget (PW-A) doublet with the polarities focussing-vertical followed by focussing-horizontal, which produces a beam spot at the target with full widths at half maximum of 6 and 22 mm, respectively. At the bottom of Fig. 2 is shown the calculated momentum distribution transmitted with the collimator settings shown in the figure, assuming a gaussian particle distribution at the target with FWHM of 6 mm and flat angular and momentum distributions. The "momentum width", defined arbitrarily as the FWHM of momentum distribution, is 6.5%.

Calculations show that for any desired acceptance, the momentum width is minimized by keeping the ratio of the momentum collimator (PW-C) aperture to the angle collimator aperture (PW-B) at the value 1.9. This minimized momentum width is shown as a function of acceptance in Fig. 3. We note that the momentum width in Fig. 2 could have been minimized to 4.9% by proper adjustment of the collimators with no change in acceptance. In Fig. 4, the momentum width is plotted as a function of the momentum collimator (PW-C) aperture. Both Figs. 3 and 4 illustrate that theoretically the minimum achievable momentum width is 2%, a limit which results from the contribution of the beam size at the target. Actually, the minimum momentum width is about 5%, because it has been observed that for settings of the angle collimator (PW-B) of less than 3 mm, the momentum width begins to increase, presumably due to the increasing relative contribution of electrons created by hadrons in the surface of the angle collimator.

The positron yield and momentum width were measured for the conditions of Fig. 2 at a secondary momentum of 15.8 GeV/c at a time when the beam was tuned for positive secondaries. The yield was measured to be 2400 positrons per 10^{10} incident protons for the acceptance value of 0.106 μster-%. The momentum width was measured by the width of the signal in a lead glass counter after corrections for the broadening arising from the lead glass resolution (5.6%) and the effect of a 1.2 radiation length lead radiator in front of the lead glass. The measured momentum width was 7.5%, to be compared with the prediction of 6.5%. The discrepancy is small and could result from subtle effects in the beam optics that were not simulated (for example, slit scattering), or from the uncertainty in unfolding the lead glass resolution due to the preradiator.

In Fig. 5, the positron, hadron, and muon content of the beam is shown as a function of momentum up to 92 GeV/c. The positron yields agree with those measured in the electron beam in Proton East, after scaling by all the different geometrical factors. The electrons and pions were concentrated in a spot of measured size 8 x 4 mm (horizontal x vertical, FWHM). However, the muons were spread rather diffusely in a circle of diameter about 25 cm and undoubtedly had a large momentum spread. In Fig. 5 the "core" of the beam is arbitrarily defined as a 6.3 cm by 6.3 cm square (one lead glass counter cross section of Experiment 95).

The absolute momentum of the beam was measured by two independent methods. In the first method, the 400 GeV proton beam was used to calibrate the bending magnets which select the momentum in the beam. These magnets are less than 1/2% saturated at 400 GeV. Linearity of field with current down to 16 GeV was then assumed (i.e., no hysteresis), and the momentum was simply determined by the current ratio as measured by precision shunts. This method yielded (15.8 ± 0.2) GeV/c for the most common operating momentum. In the second method, the deflection of the beam by magnets in both arms of Experiment 95 was measured. These magnets had been field mapped at a current close to the current at which the deflection was measured. This method yielded (15.5 ± 0.2) GeV/c. Thus the beam momentum is known to about $\pm$ 2.0%.

A number of properties of the beam have not been studied at all, either in theory or in practice. The beam is partially momentum-recombined (by the 2 mr reverse bend in PW-C), but no calculations of the position-momentum correlation at the final focus have been made. The two quadrupole doublets in the secondary beam were set by calculation to achieve a point-to-parallel-to-point tune, but no systematic quadrupole tuning has been done.

Because neither the target nor "dump" (the collimator in PW-B) are shielded, the primary proton intensity on the target is normally limited to 2×10^{10} protons per pulse. Brief runs (i.e., one shift) of 10^{11} protons per pulse are allowed. Hardening the enclosures for steady running at high intensities is impossible without digging and architectural revisions.

Further information

Additional information about the beam, including recent data not incorporated in this report, are available from Jon Hawkins, Proton Department, who is now the liaison physicist for the beam. All inquiries should be directed to him.

Reference

[1] B. Cox and C. T. Murphy, Nucl. Instr. and Methods, 136, 35 (1976).

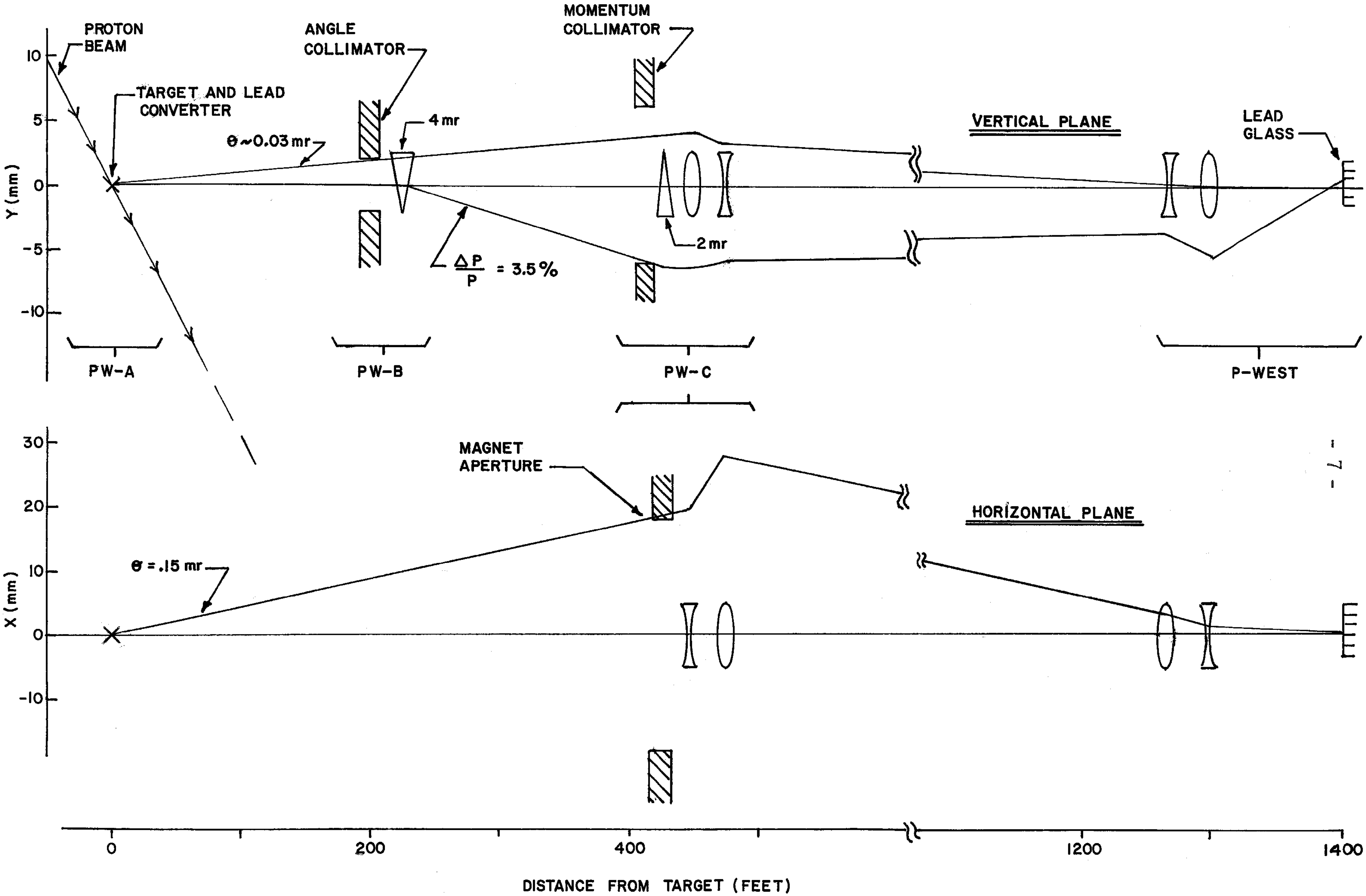
PROTON BEAM
TARGET AND LEAD CONVERTER
ANGLE COLLIMATOR
MOMENTUM COLLIMATOR
4 mr
θ~0.03 mr
2 mr
ΔP/P = 3.5%
VERTICAL PLANE
LEAD GLASS
Y (mm)
PW-A
PW-B
PW-C
P-WEST
MAGNET APERTURE
HORIZONTAL PLANE
θ = .15 mr
X (mm)
DISTANCE FROM TARGET (FEET)

FIGURE 1

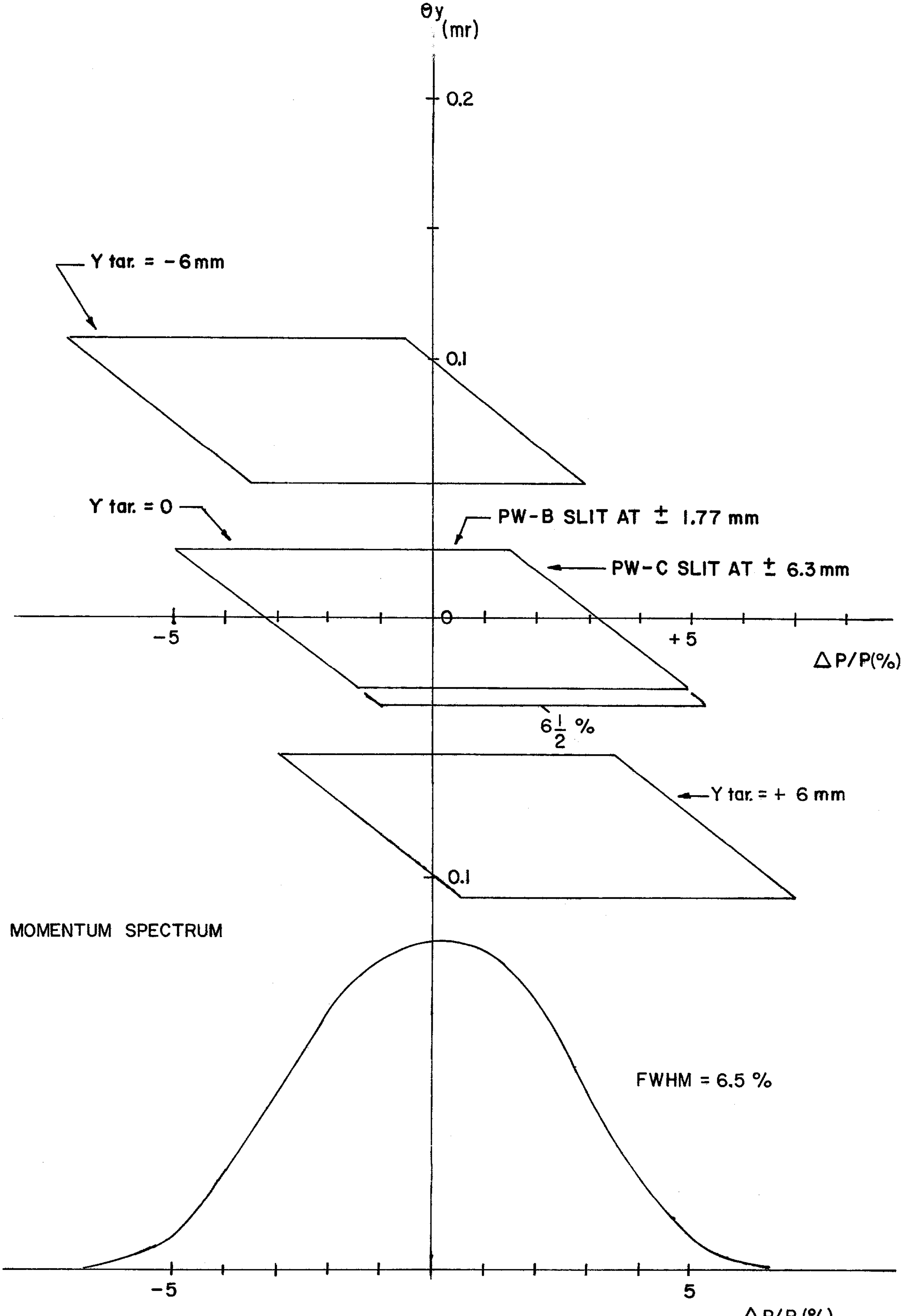
θy (mr)
0.2
Y tar. = −6 mm
0.1
Y tar. = 0
PW-B SLIT AT ± 1.77 mm
PW-C SLIT AT ± 6.3 mm
0
−5
+5
ΔP/P(%)
6 1/2 %
Y tar. = + 6 mm
0.1
MOMENTUM SPECTRUM
FWHM = 6.5 %
−5
5
ΔP/P (%)

FIGURE 2

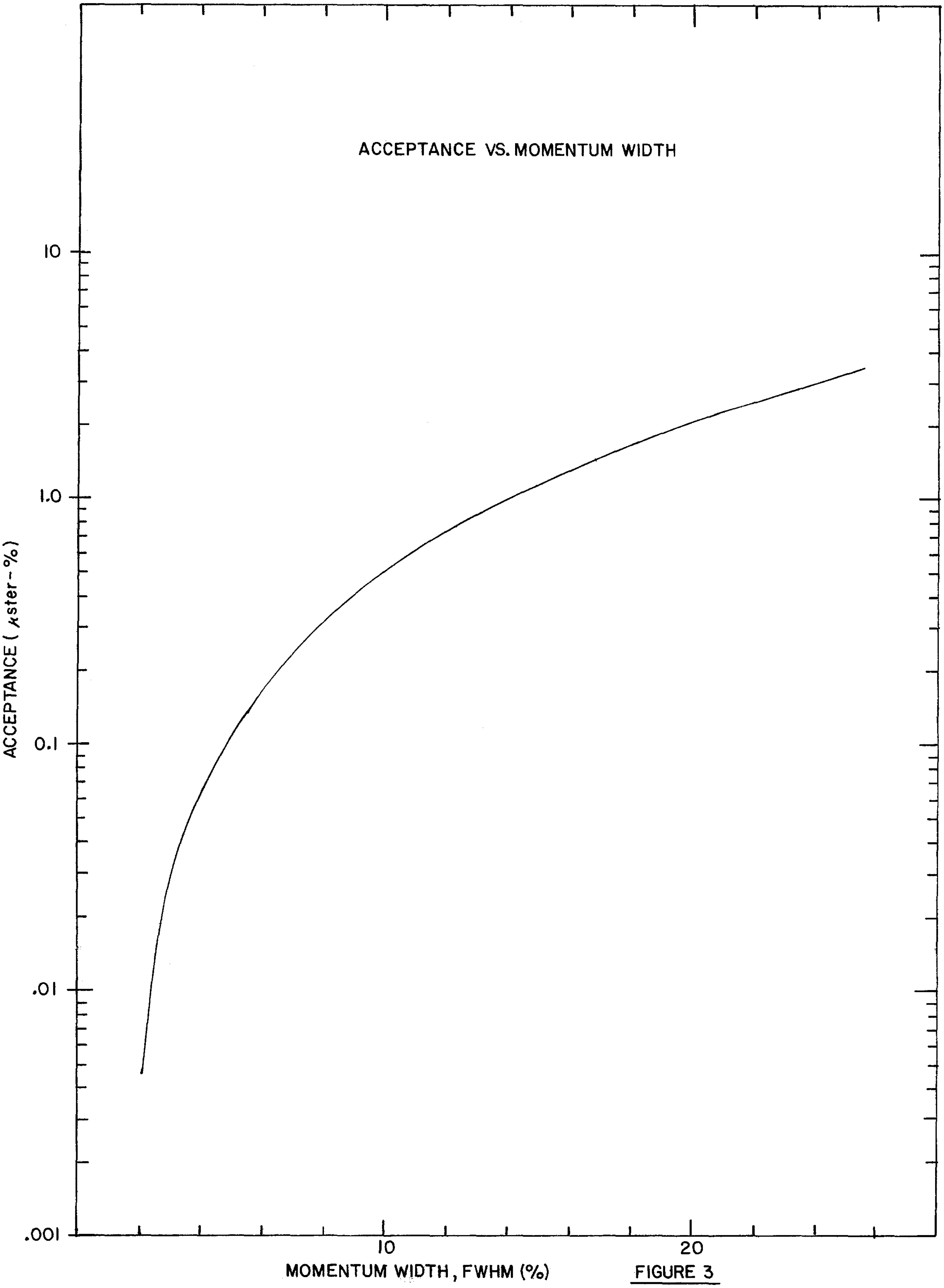
ACCEPTANCE VS. MOMENTUM WIDTH
10
1.0
0.1
.01
.001
ACCEPTANCE (μster - %)
10
20
MOMENTUM WIDTH, FWHM (%)

FIGURE 3

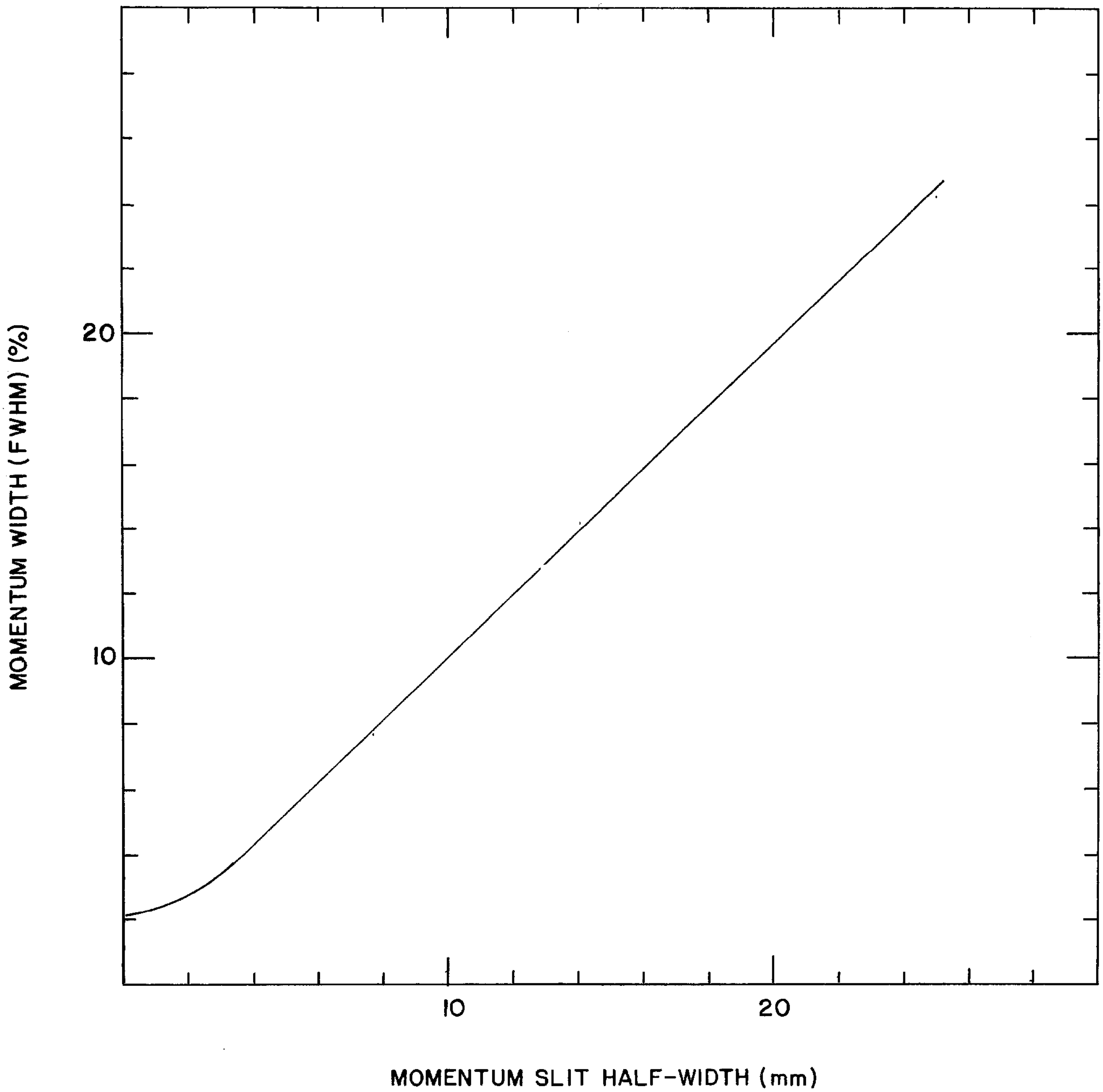

FIGURE 4

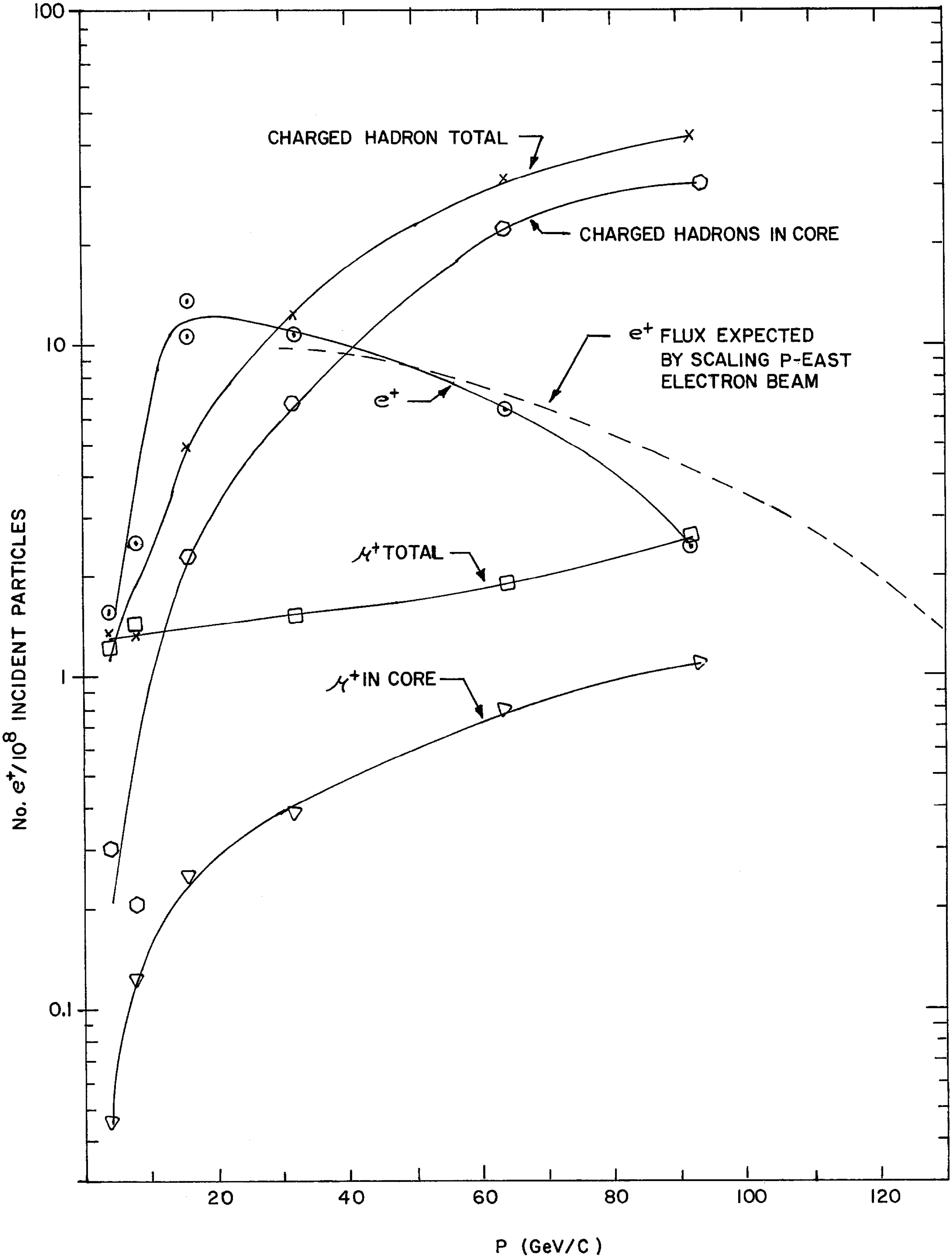
100
10
1
0.1
No. e+/10^8 INCIDENT PARTICLES
CHARGED HADRON TOTAL
CHARGED HADRONS IN CORE
e+ FLUX EXPECTED
BY SCALING P-EAST
ELECTRON BEAM
e+
μ+ TOTAL
μ+ IN CORE
20
40
60
80
100
120
P (GeV/C)

FIGURE 5